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13. SUPPLEMENTARY NOTES

NA

14. ABSTRACT

Unsteady aerodynamic computational models for aeroelastic phenomena such as flutter and limit cycle oscillations are complex and high dimensional. Under this grant, reduced order models are being developed that offer increased physical insight and greatly reduced computational cost. Transonic flows are emphasized because of their practical importance and significant technical challenge.

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15. SUBJECT TERMS

Limit Cycle Oscillations, Nonlinear Aeroelasticity, Reduced Order Models, Transonic, Unsteady Aerodynamics

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Final Technical Report
Limit Cycle Oscillations (LCO) and Nonlinear Aeroelastic Response: Reduced Order Models

AFOSR Grant Number F49620-97-1-0063

Earl H. Dowell
Duke University

September, 2001

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SCHOOL OF ENGINEERING

Relevancy

- Objective: To construct reduced order models (ROM) of unsteady aerodynamic forces to achieve orders of magnitude reduction in computational cost and model degrees of freedom

- A key enabling methodology to analyze and design for transonic flutter and limit cycle oscillations (LCO)

Relevancy

- Five years ago, such work was pioneered at Duke. Now several research groups are pursuing such work. For example,

  Dr. Philip Beran, AFRL
  Dr. John Kim, Boeing

- A systematic approach has been taken, starting from two-dimensional models and adding the effects of compressibility, shock wave motion and now

  - large shock motions
  - viscosity

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Relevancy

- Three dimensional flows have been modeled within the small shock motion approximation.
- Applications to aircraft systems (including UCAV), space launch vehicles (subsonic to hypersonic) and weapons such as aircraft stores.

Background Information and Partnerships

- Traditional approaches are based upon classical theory that ignores shock waves and viscosity

or

More elaborate CFD models that are very expensive computationally and thus not suitable for engineering analysis and design.

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Background Information and Partnerships

- We are collaborating with industry and government (AFRL and NASA) through reports to the Aerospace Flutter and Dynamics Council and as a partner with ZONA Technology (funded by a STTR grant).

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Innovation In Science

- First work to show how one can dramatically reduce the size, complexity and cost of physically sophisticated CFD models.

- Typical results for 2D and 3D flow

First Figure: Flutter boundary for an airfoil with control surface freeplay/reduced velocity (or dynamic pressure) vs Mach number.

Innovation In Science

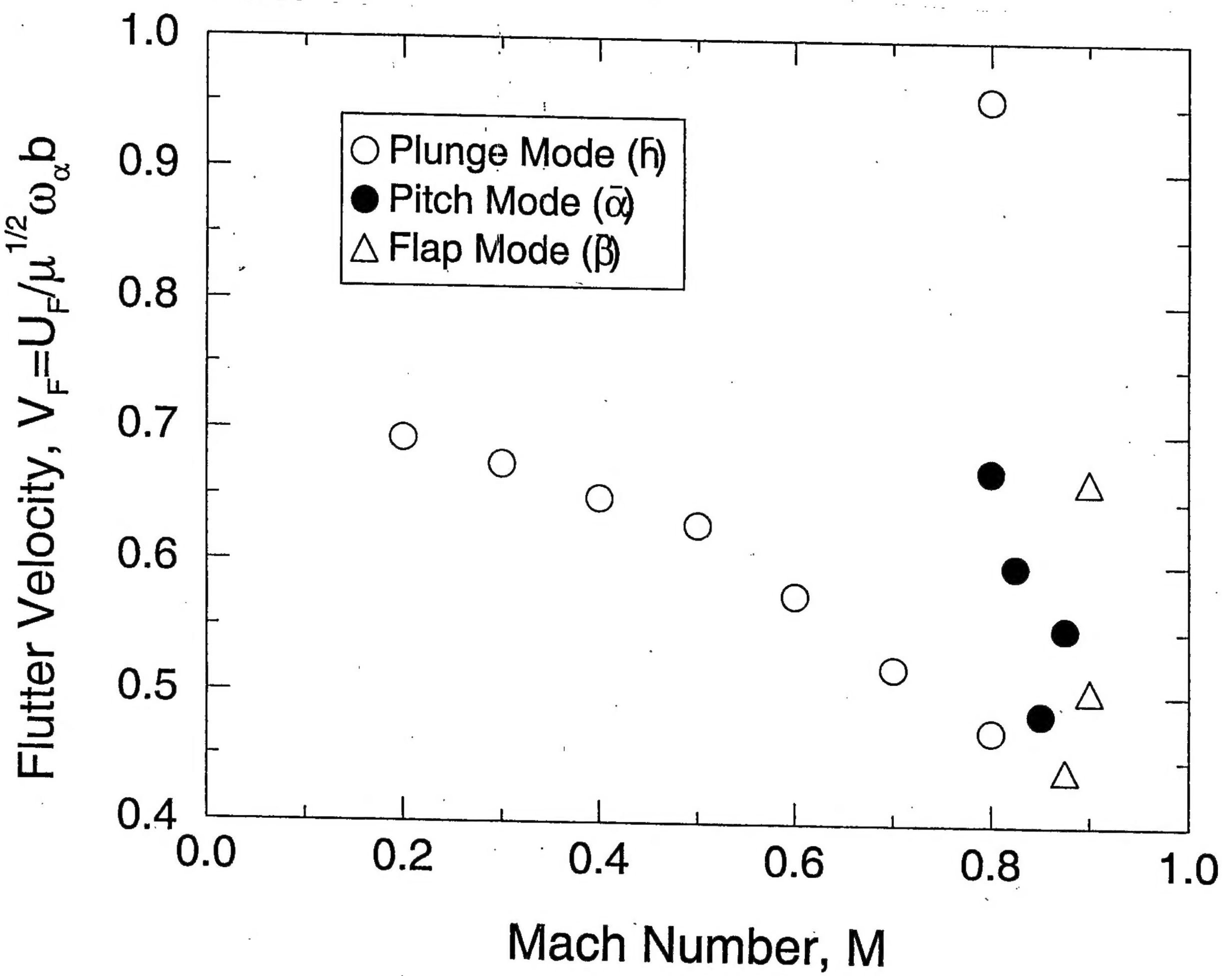
- Note rapid change in the most critical structural mode in the transonic range. Such behavior has been reported in experiments, but this is first systematic theoretical result. LCO results have also been obtained for this configuration.

Next Figure: Flutter boundary of a wing in three dimensional transonic flow.

Innovation In Science

- Flutter calculations with a POD/ROM model are no more expensive and the model size is no larger for 3D flow than for 2D flow. Of course, constructing a 3D vs a 2D POD/ROM is conceptually more complex and somewhat (factor of 2 to 3) more computationally costly.

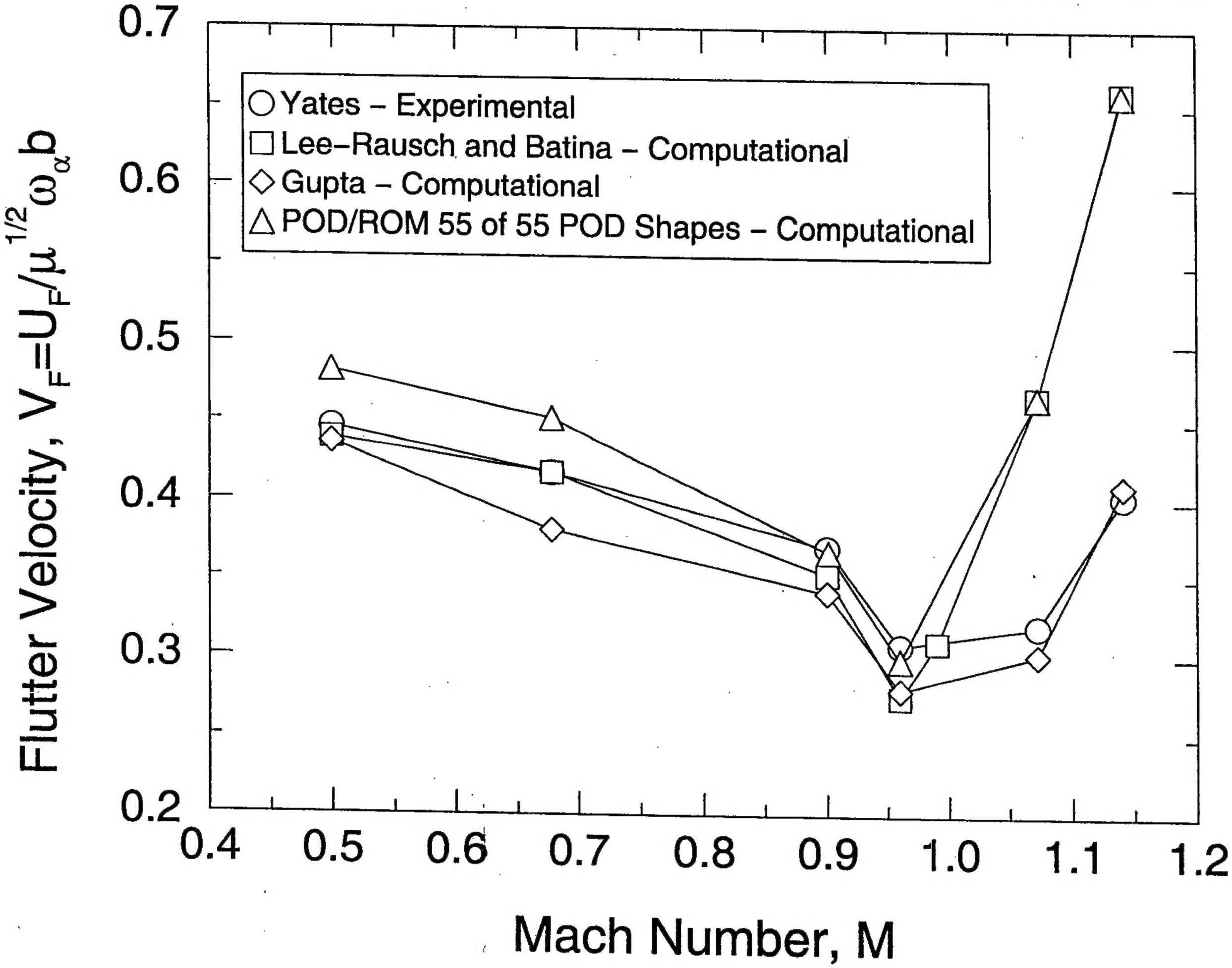
Mach Number Flutter Trend



Flutter Speed
vs
Mach Number

Chart #4

Mach Number Flutter Trend for AGARD 445.6 Wing "Weakened Configuration"



Flutter Speed
vs
Mach Number

Chart #4 (cont'd)

Innovation In Design

- POD/ROM models make transonic flutter and LCO analysis feasible for engineering design.
- POD/ROM methods are expected to impact currently operational flight vehicles (F-16 and F-18) and also future aerospacecraft (JSF, UCAV, new launch vehicles).
- Flutter and LCO are important drivers to these developments, but gust response and design of smart structures will also substantially benefit.